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A DATA BASE SIZING METHODOLOGY APPLIED TO THE ARMY TERRAIN INFO--ETC(U)

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A data base sizing methodology applied to the Army terrain information system (ARTINS)

Regis J. Orsinger

JUNE 1978

U.S. ARMY CORPS OF ENGINEERS
ENGINEER TOPOGRAPHIC LABORATORIES
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The objective of this report is to describe a methodology for estimating the storage requirements of a terrain data base as a function of geographic location and areal extent. This is done within the context of the development of a tactical data system called the Army Terrain Information System (ARTINS). The conclusions are: (1) The feasibility of storing a large terrain data base on militarized, or commercial, random access devices is clearly demonstrated;

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(2) A predictive methodology can be employed quickly and cheaply to estimate terrain data base storage requirements; (3) The total storage requirement is relatively insensitive to changes in horizontal spacing in the range beyond 125 meters; and (4) The storage requirement attributed to feature data can be dramatically reduced by modifying the required level of detail and/or the criteria for including and segmenting features.

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PREFACE

The effort described in the report was conducted under the authority of Project 4A762707A855.

The analysis described herein was conducted by Regis J. Orsinger, with valuable assistance from Barbara A. Embrey, Leroy J. Morkes, and Richard Uhrig, of the U.S. Army Engineer Topographic Laboratories.

The work was performed during June 1977 and February 1978.

A DATA BASE SIZING METHODOLOGY APPLIED TO THE ARMY TERRAIN INFORMATION SYSTEM (ARTINS)

INTRODUCTION

Although technological advancements have made large data bases appear less awesome in recent years, a good estimate of the data base storage requirement is still a critcal input to the system design process. The object of this report is to describe a methodology for estimating the storage requirement of a terrain data base as a function of geographic location and areal extent.

Less than a decade ago, the automation of many information systems was delayed because of massive data base storage requirements. Since then, users of mass storage devices have enjoyed substantially larger capacities at lower costs per stored bit and the use of data base management software has become more widespread. Although this software is characterized by a wide range of features and capabilities, the general trend has been toward increased sophistication and flexibility. As a result, such software has made the effective and efficient management of large data bases a reality for many users who were formerly confronted with seemingly insurmountable storage requirements.

BACKGROUND

The Army Terrain Information System (ARTINS) is a tactical data system that is being designed to function at the Echelon Above Corps (EAC) with user access possibly extending down to Division level. Terrain analysis will be a major system function. The system will also act as a central repository for the digital terrain data that are required by other tactical data systems and weapons systems. The ARTINS project is in the concept validation stage of advanced development. Periodically in the past, attempts have been made to estimate the terrain data base storage requirements for the ARTINS. The most recent attempt was completed in 1975.[1] Since then, system design changes and refinements have nullified previous estimates. In addition, procedures for estimating the prevalence of point and linear terrain features have been improved. These refinements have been incorporated into the methodology outlined herein. It is hoped that a firmer basis for subsequent sizing estimates will result from these efforts.

DATA BASE DESCRIPTION

GENERAL

The data base that is of interest contains terrain data that can be logically separated into two general categories: areal data and feature data. Within the context of this report terrain characteristics, which include soil types, vegetation characteristics, and land use, that can be digitized in a grid cell format are areal data. Because it is most often produced on a regular grid, digital elevation is also included in this category.

[1] R.J. Orsinger, A.C. Gunther, J.B. Grubbs II, *The Army Terrain Information System (ARTINS) - Data Base Storage Requirements*, U.S. Army Engineer Topographic Laboratories, ETL-0050, March 1976, AD-AO24 554.

Feature data can be divided into two subcategories: linear feature data and point feature data. Linear features (pipelines, roads, railroads, and waterways) can be digitally represented as a series of line segments. Point features (bridges, buildings, and fords) occupy a point location on the ground. Under this definition, many point features do occupy a finite area and are precisely positioned at some map scales. However, these factors are not as critical in terrain intelligence activities as they are in the cartographic process.

AREAL DATA

Areal data is organized into logical storage blocks comprising 1600 grid cells, or pixels, arranged in a square (40 by 40) array. A cell 125 by 125 meters is being used in ongoing experimental work. This size was selected primarily because it was consistent with known accuracy requirements of some other tactical data systems. The logical storage block covers an area 5 kilometers (km) square when this cell size is employed. A total of 400 logical storage blocks is needed to cover a complete 100- by 100-km square. If further research proves this cell size to be inappropriate, the storage requirement will change. This requirement varies inversely with the cell size being utilized. The effect of cell size on the number of logical storage blocks is illustrated in table 1.

Table 1. Relationship of Cell Size to Number of Logical Storage Blocks.

Cell Size (m)	Ground Coverage of One Logical Storage Block (km)	Number of Logical Storage Blocks In one 100 X 100 km Square
50 X 50	2 X 2	2500
100 X 100	4 X 4	625
125 X 125	5 X 5	400
250 X 250	10 X 10	100
500 X 500	20 X 20	25

ELEVATION DATA The surface upon which all other terrain data are superimposed is represented digitally by elevation data. The stored elevations are actually spot elevations, in meters, of the southwest corners of the grid cells. Each elevation is stored as an integer quantity in two bytes, or one 16-bit word. Data compaction techniques can be used to reduce the bits per stored elevation.[2] However, no such techniques are assumed here because an upper limit on the storage estimate for elevation data is desired. This upper limit will provide a baseline for subsequent analyses of data compaction/processing trade-offs that arise from using data compaction techniques.

[2] J.L. Junkins, G.W. Miller, J.R. Jancaitis, "A Weighting Function Approach to Modeling of Irregular Surfaces", *Journal of Geophysical Research*, Vol 78, No.11, April 10, 1973.

SOIL DATA Soil type can be easily encoded into one byte per grid cell. Soil strength categories appropriate to mobility analysis could also be encoded along with soil type in a single byte.

VEGETATION DATA One byte per grid cell would be needed to store a vegetation type encoded with height, stem spacing, and stem diameter categories.

LAND USE DATA Land use data consist of a two-digit code and are subdivided into urban and rural groupings. One byte per grid cell is adequate to store these data.

FEATURE DATA Unlike areal terrain characteristics, feature data may not exist everywhere. As a result, feature data are not organized into logical storage blocks. Rather, these data are stored in various files characterized by different record lengths (see appendix A). It should be noted that additions and deletions of features as well as alterations to the level of detail of features can be expected in the future. The list in appendix A does, however, constitute a representative list of digital terrain data, and the storage estimate associated with the list should serve as a solid baseline against which subsequent design changes can be analyzed. The data describing each specific feature are keyed to the appropriate ground location and orientation by means of stored coordinate values. In this way, the feature data can be readily overlaid on the areal data. In the case of linear features, the ability to overlay is achieved by storing the coordinate values of starting and ending points of each line segment. The segmenting criteria that were followed in this study are specified in appendix B. One coordinate value is stored for each point feature.

DATA BASE STRUCTURE

GENERAL A master file plays a key role in the data base structure. Through use of this file, feature data can be associated with a specific geographic location. If so desired, these feature data can be readily identified with the appropriate areal data. In figure 1, the feature files appear as rectangles and the areal files appear as circles.

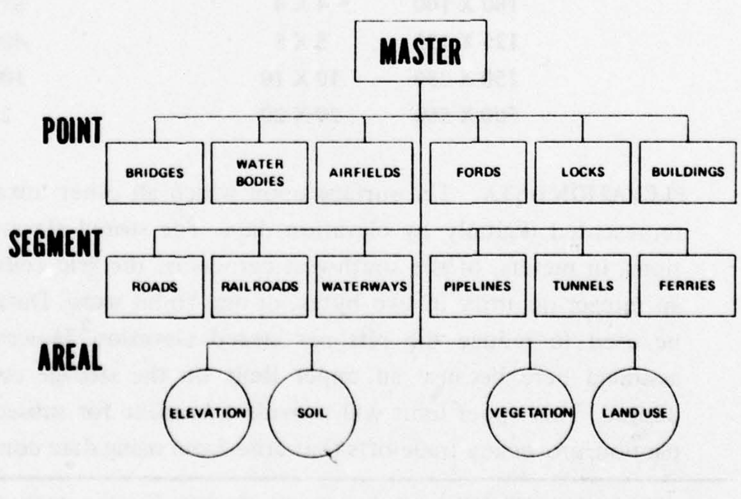

Figure 1. Data Base Structure

MASTER DATA

The master file is similar to the areal files in that the master data are also organized into logical storage blocks of identical dimensions. The master data are made up of several bits, with different bits corresponding to specific point and linear features. If no features exist in a given pixel, all bits are set to zero. However, if a road crosses over a stream in a given pixel, the bits corresponding to roads, waterways, and bridges are flagged by setting each to one. If no other features are present, all other bits would be set to zero. A minimum of 12 bits is required to accommodate all feature files identified in figure 1. Since the use of a 16-bit minicomputer is assumed, the data must be encoded in no less than two bytes per grid cell. This permits expansion of up to four additional feature files without increasing the storage requirement for master data. The addition of five or more feature files will increase the number of bytes per grid cell by at least one.

STUDY APPROACH

RATIONALE

When the grid cell approach is used, the problem of estimating the storage requirement of areal data is essentially solved, once the level of detail has been established for the digital data base. At that point, the storage requirement can be considered strictly a function of cell size and extent of geographic coverage. On the other hand, feature data estimates are also heavily dependent on the land uses that are characteristic of a particular region. For example, the density of features such as bridges and waterways is much greater in Central Europe than it is in North Africa. As a result, any estimate of the storage requirement associated with feature data should account for these geographic variations. For this reason, a statistical approach was selected for obtaining regional estimates of feature counts per unit area for those features identified in appendix A.

STATISTICAL METHODOLOGY

An irregular area in Western Europe covered by thirty-one 1:50,000 topographic maps (12 X 20 minutes) was identified as the primary area of interest. Using random number tables, five map sheets were selected from within this area. For each map sheet, 15 grid squares, or square kilometers, were randomly selected using random number tables. The 75 grid squares that were identified in this way were then analyzed for the frequency of occurrence of the pre-selected features. Although only map information was used here, more accurate results can be expected by using good quality aerial photographs and collateral source materials.

A visual inspection of the resultant histograms (see appendix C) suggested that the exponential distribution would be appropriate in most cases. Subsequent curve-fitting confirmed this. An exponential function of the form

$$f(x) = \alpha e^{-\beta x} \qquad \alpha, \beta, x > 0 \qquad (1)$$

was successfully employed in these cases. To insure that basic assumptions about probability densities were not violated, the exponential function was normalized by multiplication with the factor β/α

$$g(x) = \frac{\beta}{\alpha} f(x) = \beta e^{-\beta x} \quad (2)$$

The mean of a probability density of this form is given by $1/\beta$. Mean values were obtained for each feature in this way. These mean values were then considered along with the extent of the area of interest in developing the feature data storage requirement. Features that did not occur in the sample or that occurred very rarely were ignored in arriving at the storage estimate.

The methodology described here was implemented in an economical manner. Slightly more than 2 manweeks were required to complete the whole process, from map selection through to statistical analysis. The time will vary in other cases but will always be directly proportional to sample size.

RESULTS

AREAL ESTIMATE

Arriving at an estimate of the storage requirement associated with areal data was a straightforward matter. The physical sizes of the grid cells, logical storage blocks, and map sheets (at appropriate latitudes) were considered in computing these requirements. The results appear in table 2 for each type of areal data. For completeness, master data are included.

FEATURE ESTIMATE

This estimate was obtained by first determining the storage requirement, in bytes, for each linear feature segment and point feature, and then determining the expected rate of occurrence per grid square for each feature. These data were used as a basis for estimating the total storage requirement for a typical map sheet. The results are summarized in table 3.

Table 2. Estimates for Areal Data

DATA	BYTES/CELL	BYTES/MAP
Elevation	2	67,680
Soil Type	1	33,840
Vegetation Class	1	33,840
Land Use	1	33,840
Master	2	67,680
	TOTAL	236,880

Table 3. Expected Frequencies and Storage Estimates For Each Feature

FEATURE	BYTES/FEATURE	EXPECTED FREQ PER GRID SQUARE	EXPECTED BYTE COUNT PER MAP SHEET
Bridges	34	1.54	27685
Roads			
Surfaced	37	12.50	244547
Unsurfaced	37	22.46	439402
Railroads	34	2.00	35955
Waterways			
Perennial	40	7.14	151011
Intermittent	40	1.96	41454
Waterbodies	20	.96	10152
Pipelines	23		
Airfields	40		
Fords	13		
Ferries	27	.01	186
Tunnels	25	.01	172
Locks	23	.05	645
Buildings	4	25.0	52875
		TOTAL	1,004,084

The storage requirement estimates for areal and feature data are shown as a function of geographic coverage in figure 2. In addition, the total storage requirement is also shown.

SENSITIVITY TO CHANGE

It should be noted, however, that an additional storage overhead may be incurred. This overhead will vary among data base management systems. As shown on the graph, the total for a 30-map-sheet area is about 37 megabytes (MB), or about 1.2 MB per map sheet. For a 90-map-sheet area, this total increases linearly to about 112 MB. If an additional byte of areal data storage is required for each grid cell, the storage requirement is increased by about .003 MB per map sheet, or 3.05 MB for a 90-map-sheet area. This represents less than a 3 percent increase in the total storage requirement. Each additional byte (per grid cell) would increase the total by the same amount. The effects of similar increases to feature data are slightly less transparent because of the variations in frequency of occurrence and byte requirements. For instance, a 20 percent increase in the amount of data describing roads would result in an overall increase of 11 percent. Whereas, an identical increase in the amount of data describing fords or ferries would have a negligible effect on the total storage requirement. The impact of adding new features to the data base cannot be accurately predicted until the frequency of occurrence of these features is estimated for a particular geographic area of interest. This assumes that the desired level of detail is known for these new features. Clearly, features that occur often will increase the data base size significantly. Conversely, the inclusion of rare features will not increase data base size appreciably.

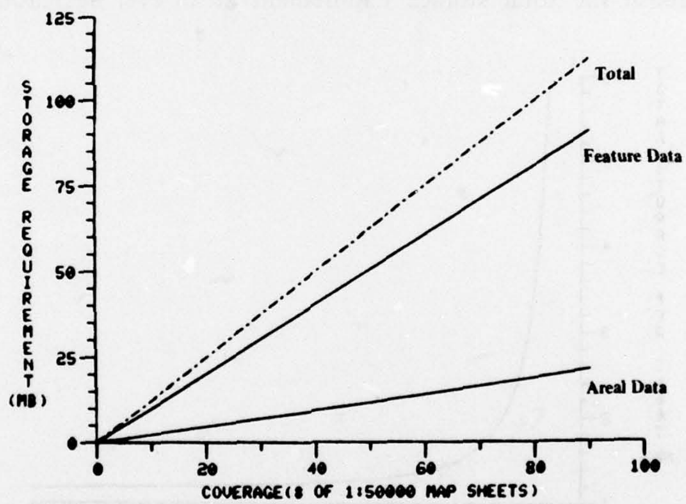

Figure 2. Storage Requirement vs Geographic Coverage

COMPARISON TO PREVIOUS ESTIMATES

All earlier attempts to estimate the size of the ARTINS data base have yielded larger predictions. The last effort yielded an estimate of 10.5 MB for each 1:50,000 map sheet.[3] The current estimate of 1 2 MB is less than one-eighth of this previous estimate. There are many reasons for this substantial reduction.

The first reason for the sharp decrease in data base size is that the horizontal spacing between stored elevation values has been changed from 50 to 125 meters. Although this has not yet been established as the optimal spacing for ARTINS applications, it is consistent with known requirements of other tactical data systems. At this stage in the ARTINS development, this spacing is considered more realistic than smaller spacings used previously. The overall effect of this was to decrease the total storage requirement. The total storage requirement, S_t, can be expressed as a function of horizontal spacing, denoted by s.

$$S_t = S_f + S_a + A/s^2 \tag{3}$$

Here, S_f is the storage estimate associated with feature data, S_a is the storage estimate associated with areal data less elevation data, and A is the area of the digitized region. It is evident from the curve in figure 3 that increases in the horizontal spacing beyond 125 meters diminish the total storage requirement at an ever decreasing rate. For

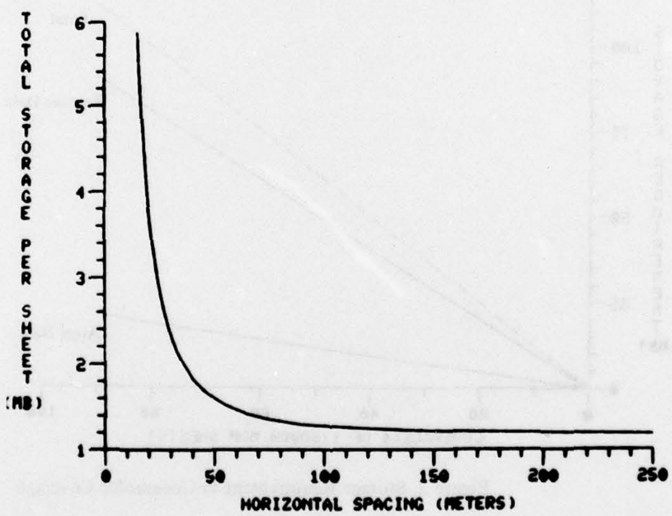

Figure 3. Total Storage per Map Sheet vs Horixontal Spacing

[3]R.J. Orsinger, A.C. Gunther, J.B. Grubbs II, *The Army Terrain Information System (ARTINS) - Data Base Storage Requirements*, U.S. Army Engineer Topographic Laboratories, ETL-0050, March 1976.

example, if the spacing is doubled to 250 meters, data base size would decrease by 4 percent. On the other hand, if the spacing is decreased to 50 meters, the data base size would increase by 29 percent.

The second reason for the sharp decrease in data base size has its roots in the character, or byte, requirements associated with the various types of terrain data. Previous byte requirements included much data that is of interest in a cartographic and/or intelligence production environment at DoD level. Data not considered critical at tactical echelons was deleted. The use of integer codes rather than alphanumeric characters made further reductions possible.

HARDWARE REQUIREMENTS

The Control Data Corporation has recently marketed the 640 Military Disk Drive. The capacity of a single drive is 640 million bits, or 80 MB. In addition, CDC offers an expansion option that permits the addition of three more disk drives, with a resultant system capacity of 320 MB. Several other vendors, in addition to CDC, offer commercial disk systems with comparable capacities.

Even if provisions are made for 100 percent expansion, the ARTINS data base, as described in this report, will fit easily on four disk drives. About 96 MB would still be available for software and scratch file space. This assumes a Corps area of responsibility covering 90 map sheets. This is the approximate number of 1:50,000 map sheets needed to cover an area 140 km wide, 250 km deep, and extending 150 km into enemy territory. This estimate is valid for midlatitudes (45^{o} - 55^{o}), and it provides for an overlap with adjacent Corps. At Division level, the area of interest would probably cover 60 map sheets or less. This constitutes a storage requirement of about 72 MB for the region identified in this study. Although this could be satisified by one disk drive, a configuration featuring two disk drives would permit some data base growth and would probably be more responsive to users at Division level. At the Echelon Above Corps, the area of interest may be two or three times that of Corps. It is doubtful that there is a real need to have the entire data base online continuously at this echelon, especially with remote processing capabilities at Corps and/or Division. As a result, much of this data could be stored on spare disk packs and brought online when necessary.

REDUCING STORAGE REQUIREMENTS

A number of techniques can be applied to a terrain data base to effect data compaction. A method of compacting elevation data was referred to previously. For other areal data in a cellular format, compaction could be accomplished quickly and easily by accounting for the repetition that is characteristic of these data. The storage requirement associated with linear feature data can be substantially reduced by relaxing the segmenting criteria that requires all line segments to be approximately straight.

For example, the exclusion of secondary roads and intermittent streams from the digital data base would reduce the feature storage requirement by 48 percent in the study area. Because of the possibility of a substantial savings in storage, the need for these types of digital data should be closely evaluated.

The study conclusions are as follows:

CONCLUSIONS

(1) The feasibility of storing a large terrain data base on militarized, or commercial, random access devices is clearly demonstrated.

(2) A predictive methodology can be employed quickly and cheaply to estimate terrain data base storage requirements.

(3) The total storage requirement is relatively insensitive to changes in horizontal spacing in the range beyond 125 meters.

(4) The storage requirement attributed to feature data can be reduced dramatically by modifying the required level of detail and/or the criteria for including and segmenting features.

APPENDIX A.

FEATURE DATA DETAILS

The coordinates of the starting and ending points for each line segment will be stored for all types of linear feature data. Other feature-dependent characteristics will also be digitally encoded. These characteristics are listed below for each linear feature. The number of bytes required to describe fully a particular segment appears in parentheses after the linear feature name.

LINEAR FEATURE CHARACTERISTICS

1. **ROADS** (37 bytes)
   - a. Type
   - b. Width
     - (1) Traveled way
     - (2) Shoulder
   - c. Surface material
     - (1) Traveled way
     - (2) Shoulder
   - d. Road classification
   - e. Segment length
   - f. Route number designator
   - g. Status
   - h. Minimum curvature
   - i. Maximum grade
2. **RAILROADS** (34 bytes)
   - a. Ballast material
   - b. Status
   - c. Segment length
   - d. Minimum curvature
   - e. Maximum grade
   - f. Route number
   - g. Number of tracks
   - h. Rail gage

3. **WATERWAYS** (40 bytes)

   a. Depth (max, min, mean)

   b. Bank slopes (left and right)

   c. Bank material (left and right)

   d. Bottom material

   e. Obstacle type

   f. Width (max, min)

   g. Potability

   h. Water velocity

   i. Segment length

4. **PIPELINES** (23 bytes)

   a. Type

   b. Position

   c. Status

   d. Number of pipes

   e. Diameter

5. **TUNNELS** (25 bytes)

   a. Type

   b. Width of traveled way

   c. Vertical clearance

   d. Number of lanes

   e. Length

   f. Primary usage

6. **FERRIES** (27 bytes)

   a. Width

   b. Type

   c. Tonnage capacity

   d. Load classification

   e. Status

   f. Crossing time (round trip)

   g. Number of ferries

The coordinates of a point location are stored for each point feature. Other feature-dependent characteristics that are digitally encoded are listed below for each point feature. Again the number of bytes required to describe fully a particular segment appears in parentheses after the point feature name.

POINT FEATURE CHARACTERISTICS

1. **BRIDGES** (34 bytes)

   a. Type

   b. Length

   c. Number of spans

   d. Load classification (one-way and two-way)

   e. Construction material

      (1) Superstructure
      (2) Supports
      (3) Abutments

   f. Width of traveled way

   g. Under bridge clearance

   h. Vertical clearance

   i. Existence of demo chambers

   j. Bypassibility

   k. Status

2. **WATERBODIES** (20 bytes)

   a. Areal extent

   b. Type (dam, lake, etc.)

   c. Maximum depth

   d. Soil bank conditions

   e. Bottom composition

   f. Water potability

   g. Transportation potential

3. **AIRFIELDS** (40 bytes)

   a. Type

   b. Runways, taxiways, and hardstands

      (1) Number
      (2) Azimuth (except hardstands)
      (3) Length
      (4) Width
      (5) Status
      (6) Surface material

4. **FORDS** (13 bytes)

   a. Type

   b. Approach

   c. Status

5. **LOCKS** (23 bytes)

   a. Number of chambers

   b. Gate type

   c. Fill time

   d. Clearance time

   e. Existence of chambers

   f. Status

   g. Chamber length

   h. Chamber width

6. **BUILDINGS** (12 bytes)

   a. Height

   b. Construction material

APPENDIX B.

CRITERIA FOR SEGMENTING LINEAR FEATURE DATA

1. These guidelines apply only to those linear features that were addressed in the map feature count. They are as follows: roads, railroads, waterways, pipelines, tunnels and ferries. Similar criteria could be developed for other linear features not addressed in this report.

2. Because of the varying manner in which linear features are described, each feature is discussed separately. Some segmenting criteria were applied in all cases, however. First, to facilitate generation of digital plots, all linear features were segmented into connecting straight line segments. New segments were started when it became visually obvious that a straight line of any greater length would produce a "bad fit" to the actual orientation of the linear feature. Second, new segments were started when the data describing a given segment changed in some way. Finally, no segment started in one logical storage block and terminated in a different logical storage block. Rather, each segment was wholly contained within one and only one logical storage block. Note that a length limitation is implied here.

3. Specific segmenting criteria pertaining to each linear feature are listed below:

   a. Roads - create a new segment when there is a change in:
      (1) road type
      (2) width of traveled way
      (3) surface material of road
      (4) surface material of shoulder
      (5) shoulder width
      (6) route classification
      (7) route number designator
      (8) operational status
      (9) maximum grade

b. Railroads - create a new segment when there is a change in:

(1) ballast material
(2) operational status
(3) route number designator
(4) number of tracks
(5) rail gage
(6) maximum grade

c. Waterways - create a new segment when there is a change in:

(1) waterway depth (max, min, and mean)
(2) slopes of left and right banks
(3) material type of both banks and bottom
(4) obstacle type
(5) waterway width (max and min)
(6) water potability
(7) water velocity

d. Pipelines - create a new segment when there is a change in:

(1) type or usage
(2) position
(3) operational status
(4) diameter
(5) number of pipelines

e. Tunnels - create a new segment when there is a change in:

(1) width of traveled way
(2) vertical clearance
(3) number of lanes

f. Ferries - the data describing a given ferry should not change along the specified route. Therefore, the general criteria listed in paragraph 2 should be the only criteria applied in this case.

Appendix C. Feature Data Histograms

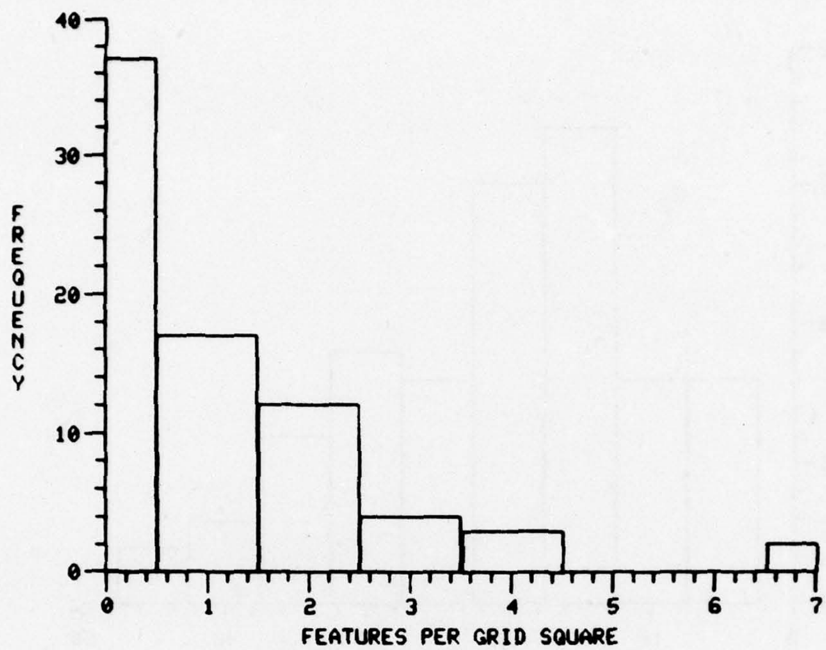

Figure C1. Bridge Histogram

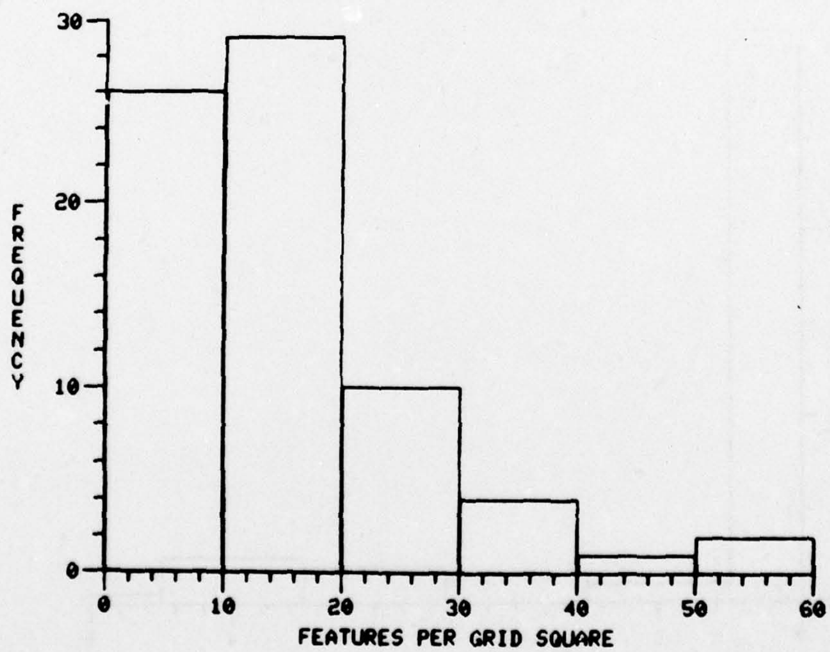

Figure C2. Surfaced Road Histogram

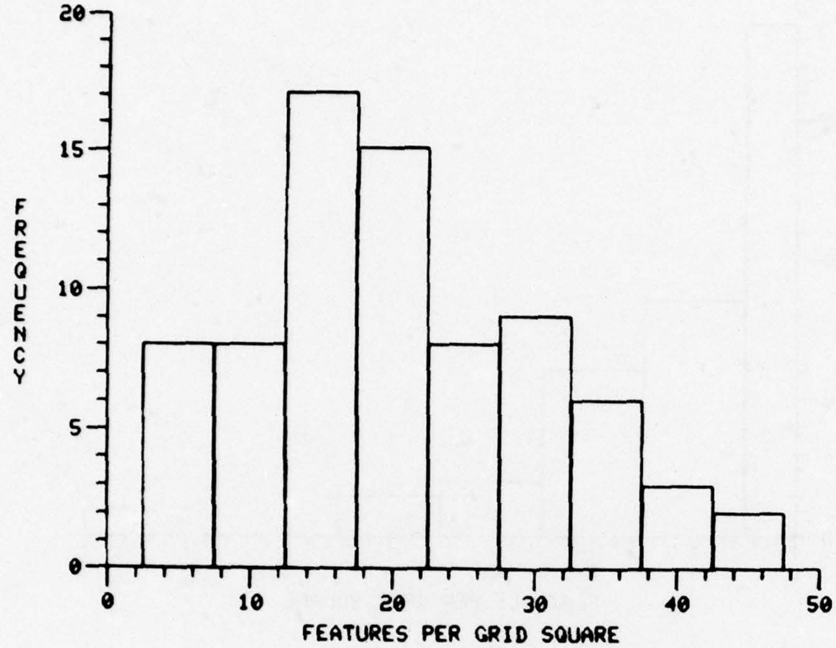

Figure C3. Unsurfaced Road Histogram

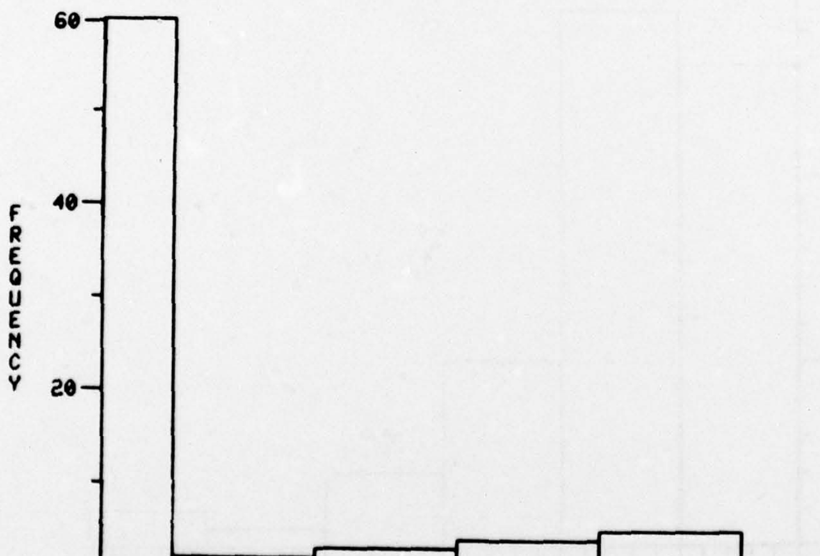

Figure C4. Railroad Histogram

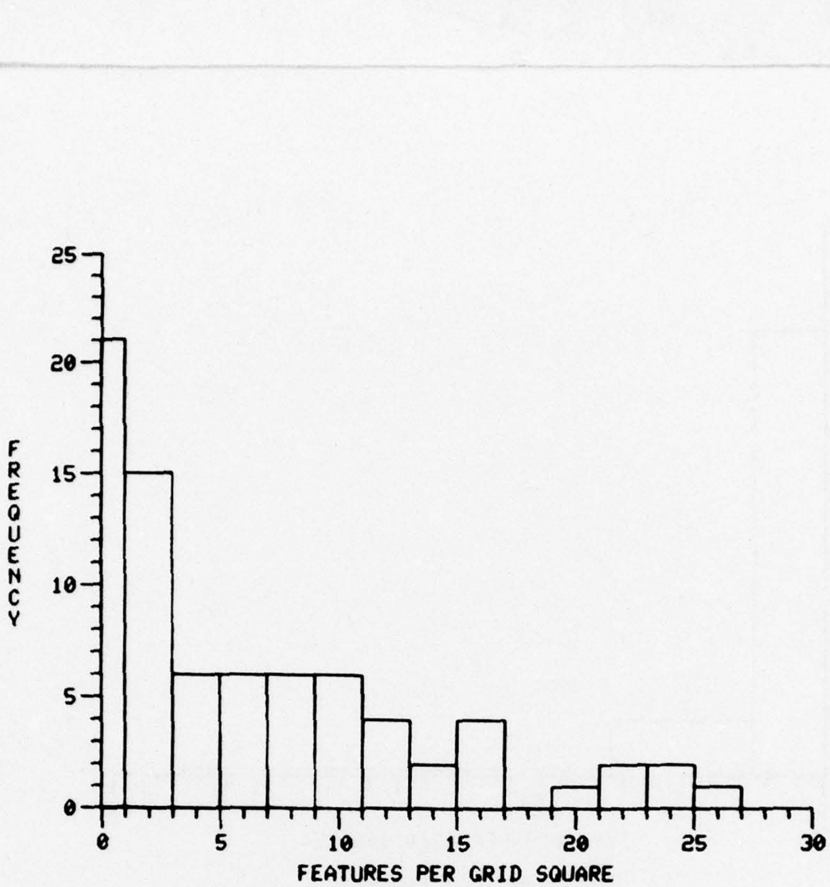

Figure C5. Perennial Waterway Histogram

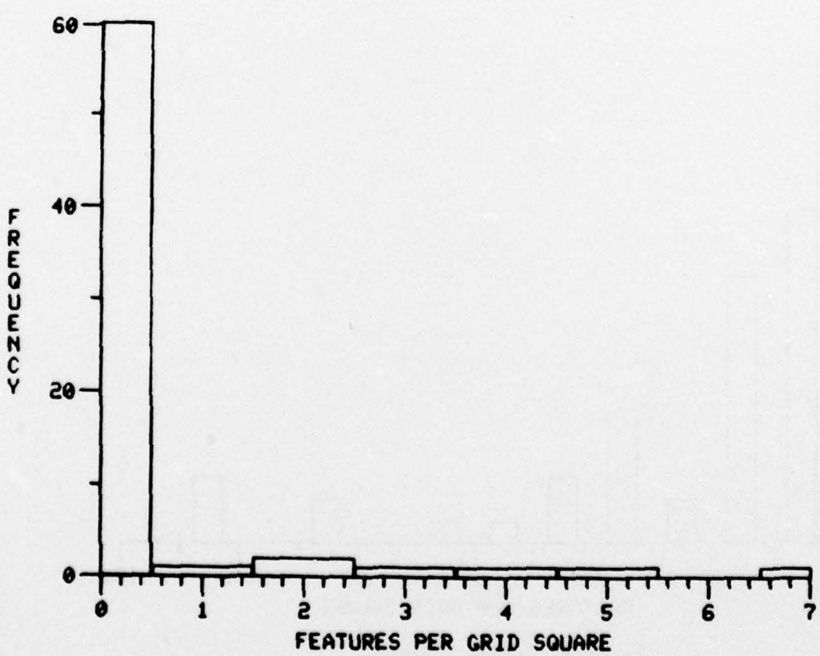

Figure C6. Intermittent Waterway Histogram

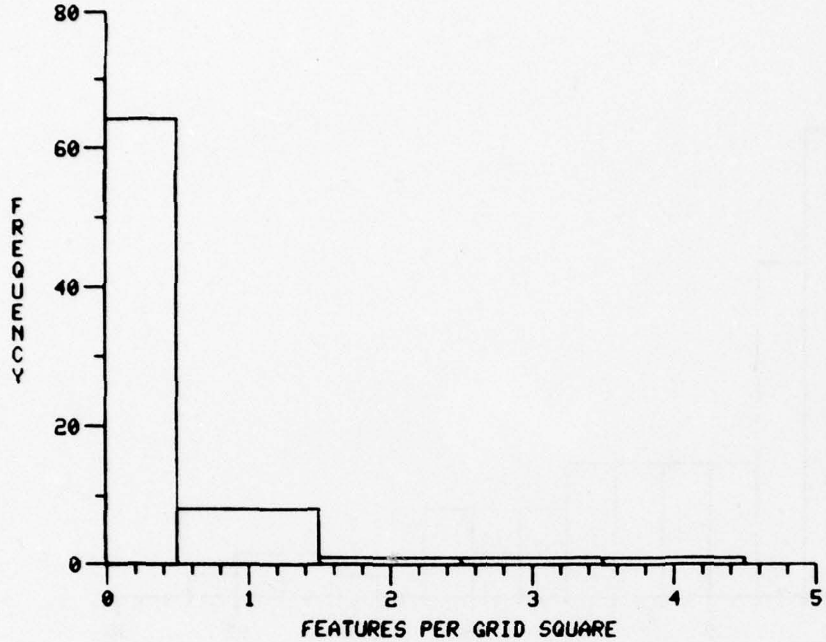

Figure C7. Waterbody Histogram

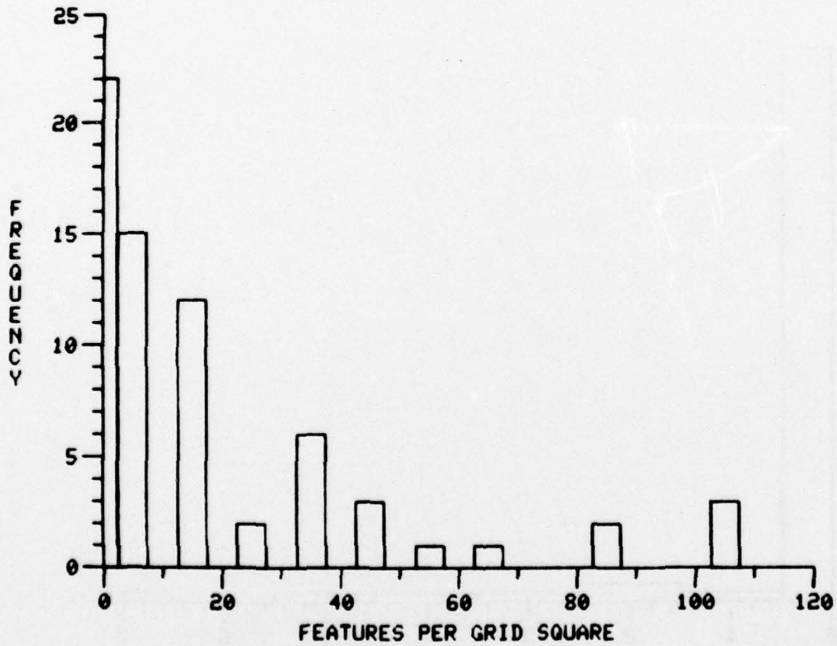

Figure C8. Building Histogram

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